A Fuzzy System for the Assessment of Human Reliability

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Abstract *— This work presents a methodology for the characterization of human reliability based on fuzzy sets concepts, which has been implemented in an innovative decision support system, providing managers with an intelligent computational tool for reducing the possibility of human errors in industrial activities. Considering that such activities can be described as operational, maintenance or inspection processes, which are composed of a set of procedures, the methodology is carried out in two levels: the process level and the procedure level. The proposed system provides a human reliability index, which allows the identification of problems that may constitute causes of human errors, as well as the indication of possible strategies for the control of potentially adverse impacts of interactions that add uncertainty and complexity to processes.*

Keywords— fuzzy sets, human reliability, industrial process safety.

1 Introduction

Human reliability has received much attention in areas such as nuclear, aviation and petrochemical industries. Although resources have been historically applied mostly in equipment reliability and process optimization, it has been realized that priority should be given to the study of human reliability, focusing on the adaptation of the equipment and the working environment to the capabilities, limitations and needs of the human being. Human error usually arises from inadequacies of the system design, such as task complexity and error-likely situations. Errors are likely to occur when the task requirements exceed human limitations regarding perception, attention, remembering, etc. Some situational characteristics may predispose operators to errors, such as inadequate workspace and training procedures, as well as poor supervision. Errors may also reflect individual differences, related to human attributes such as abilities and attitudes. Important individual factors are susceptibility to stress and inexperience, for example, which may increase tenfold the possibility of occurrence of a human error.

Studies in human reliability are generally divided into two generations [1]. First-generation methods are characterized by comparing human performance to that of a machine, associating probabilities of success or of a fault to the operators' actions. Second-generation methods extend the analysis of human reliability to cognitive systems, by considering decision levels, diagnosis processes, dexterity, knowledge and organizational factors. These are probability-based methods, which makes it difficult to establish a precise model for human fault prediction, since a large quantity of data is needed for mapping all the uncertainties inherent to human behavior.

Probabilistic analysis is used for analyzing system reliability objectively and assumes that an equipment or human failure occurs at random. A failure of a single component may occur at random; a human error, however, does not necessarily occur in that way, since a human factor is composed of a large number of attributes (or performance shaping factors) and its functional structure is very complex. By using the probabilistic approach, where the equipment and procedure are qualified, it is assumed that the operator correctly implements all the procedure's provisions and thus isolates the human factor elements.

Other works [2] have contributed to human reliability research employing Fuzzy Set Theory and the concept of possibility of failure instead of probability of failure. Lian and Wang [3] used fuzzy relations to estimate the *fuzzy probability*. Nowakowski [4][5] observed that, when applying the fuzzy approach, probabilistic interpretations of human reliability are abandoned; instead, human reliability is defined in terms of possibility measures. Wang [6] used the concept of fuzziness to evaluate human performance in an inspection task. Onisawa [7] analyzed human reliability in the events that preceded the nuclear accident in Chernobyl and showed the importance of considering the possibility approach in human reliability analysis. More recently, Onisawa [8] created a model that integrates the subjectivity in specialists' opinions to reliability analysis.

This work presents a fuzzy-based decision support system for the analysis of human reliability in operation, maintenance and inspection activities in industrial and production processes, where the human error may have a great impact on safety and on the environment. As operational, maintenance and inspection processes consist of a set of procedures, the human reliability characterization method is carried out at both process and procedure levels.
This paper comprises four additional sections. Section 2 presents the methodology, describing in detail the human reliability characterization at both process and procedure levels. Section 3 presents a decision support system developed to provide managers with computational tools for the application of the human reliability characterization method, helping them to choose the most adequate strategic actions to be taken. Section 4 discusses a case study in the oil industry and Section 5 concludes the work.

2 Proposed Methodology

This work deals with a two-level analysis of human reliability in industrial activities. On a first level, each of the operation, maintenance and inspection processes are

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analyzed as a whole; then, on a second level, human reliability is considered for every procedure that composes each of the processes.

The following sub-sections describe in details the two-level analysis contemplated by the proposed methodology.

2.1 Process Level Characterization

This module is an improved version of the process level characterization first introduced in [9].

The characterization of human reliability in a process has the objective of establishing the degree of attendance of Performance Shaping Factors (PSFs), which can be of human, technical or environmental types. Such characterization may be carried out in any category: operation, maintenance or inspection.

The method for determining the degree of attendance of a set of attributes (see Fig. 1) begins with the selection of PSFs that affect the human being. After that, experts specify, through a questionnaire, the influence of each of these factors on human reliability. By aggregating the experts' opinions about the PSFs' influences, weighed by the degree of importance of each expert, a standard degree of influence is established for each PSF. By considering the degrees for all PSFs, a Quality Standard is obtained. In a second stage, workers' opinions on the attendance of each of the PSFs are collected, also through a questionnaire, producing the degree of attendance of each PSF [9].

For human PSFs that are related to cognitive characteristics, namely intelligence, communication ability, sociability, attention, stress and anticipation, the attendance degree is determined by psychometric tests applied to each operator. It is considered that, for such type of factors, the operators opinion would correspond to a self judgment, which could result in biased information about the attendance degree. Psychometric tests are likely to provide more reliable results, since they are constructed to determine individual psychosomatic characteristics in an unbiased manner. The enhanced process level characterization method is depicted in the diagram of Fig. 1, which highlights the Psychometrics tests module, one of the significant contributions of this work.

2.2 Procedure Level Characterization

The human reliability characterization at procedure level focuses on two main objectives: establish a failure possibility index for each procedure in an operation, maintenance or inspection process, and for each of the human actions that are performed to accomplish it; and secondly, establish the degree of attendance for each worker with respect to the cognitive demands of each action within the procedure.

The characterization method requires that experts specify the failure expectation for each action, the degree of dependency of each action on the preceding one, the influence that a failure in one action may have on subsequent ones and the cognitive demands of each action. All this information is acquired through the application of questionnaires, where experts give linguistic answers such as *low*, *medium*, or *high*. The experts' opinions are aggregated and weighed by the degree of importance of each expert so as to produce, for each action, a failure possibility index and standard demand degrees with respect to the cognitive factors considered. The overall failure index for the procedure can be obtained by combining the actions indexes. By submitting the workers to psychometric tests, the degree of attendance of each cognitive factor for all operators can be determined. The method is depicted in the diagram of Fig. 2.

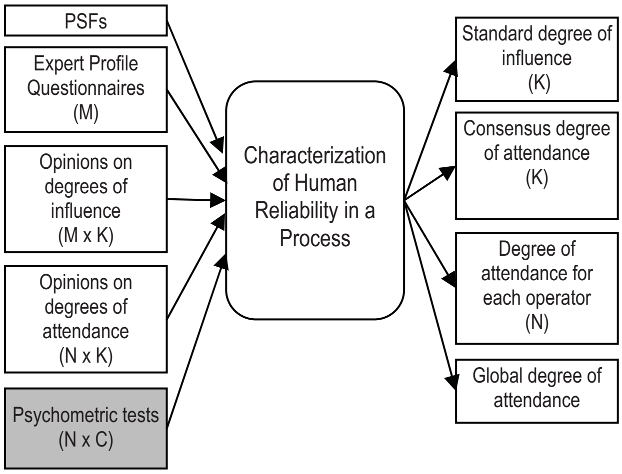

Figure 1: Characterization of Human Reliability in a Process, with K PSFs, C cognitive factors, M experts and N operators.

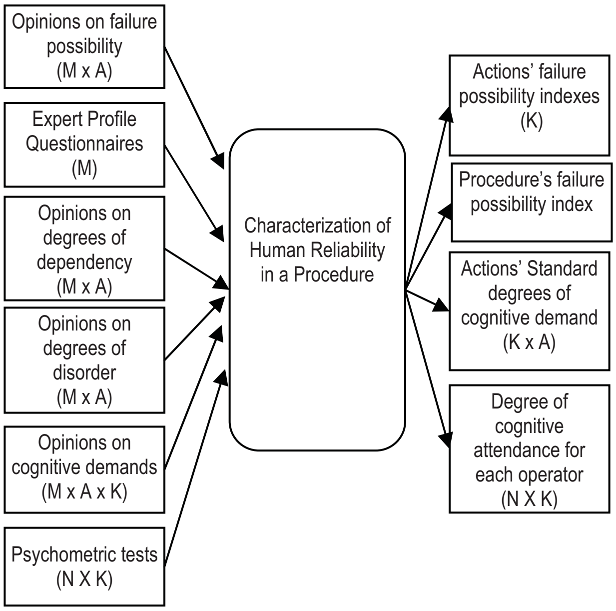

Figure 2: Characterization of Human Reliability in a Procedure, with A actions, K cognitive factors, M experts and N operators.

The procedure level characterization methodology consists of the following stages.

Establishment of a committee of decision-makers

This is one of the most important steps in the methodology, since the quality of information will depend on the experts' proficiency.

Establishment of the relative importance of each expert

This step is accomplished through an Expert Profile Identification Questionnaire (EPIQ), which consists of a set

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of questions for the evaluation of each expert's relative importance and thus assigning him a weight [10]. This weight will establish the influence of the expert's opinions on the final standard degrees and failure possibility indexes.

Choice of linguistic values for the evaluation of actions

This stage consists of choosing linguistic terms, or values, for the evaluation (by experts) of the expectation of failure of an action, its degree of dependency on the preceding one, its influence on subsequent ones and its cognitive demands. For instance, the terms used for the evaluation of the expectation of failure usually are: *very high, high, medium, low,* and *very low***.** All terms are associated to triangular fuzzy sets, defined by three parameters.

Acquirement of experts' opinions

This step consists of obtaining from the selected experts, through questionnaires, their opinions on the expectation of failure of each action, its degree of dependency on the preceding action, its influence on succeeding ones and its cognitive demands.

Application of psychometric tests to operators

Psychometric tests are applied to operators in order to obtain the degree of attendance of cognitive demands for each worker.

Fuzzy treatment of the data provided by experts and of psychometric tests results

Here, the individual prognoses from each expert for failure expectation, dependency, influence on future actions and cognitive demands are aggregated, generating a consensus for each evaluated attribute. The Hsu and Chen's model [11] is used to pool the expert's opinions: the similarity aggregation method (SAM) is used for combining the opinions of each expert. The opinion of an expert i is expressed by a fuzzy set denoted by $\tilde{A}_i$. The agreement degree (or similarity measure) $S(\tilde{A}_i, \tilde{A}_j)$ between two experts i and j can be determined by the proportion of the consistent area to the total area:

$$S(\tilde{A}i,\ \tilde{A}j) = \frac{\int_x \min(\mu_{\tilde{A}_i}(x), \mu_{\tilde{A}_j}(x))dx}{\int_x \max(\mu_{\tilde{A}_i}(x), \mu_{\tilde{A}_j}(x))dx} \tag{1}$$

Once all agreement degrees between experts are measured, an agreement matrix (AM) can be built, giving an insight into the agreement between the experts.

$$AM = \begin{bmatrix} 1 & S_{12} & S_{13} & .... & S_{1n} \\ S_{21} & 1 & S_{23} & .... & S_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ S_{n1} & S_{n2} & S_{n3} & .... & 1 \end{bmatrix} \tag{2}$$

The average agreement degree AAD_i of expert E_i (i = 1 to n) is given by:

$$AAD_i = \frac{1}{n-1}\sum_{\substack{j=1 \\ j\neq i}}^{n} S_{ij} \tag{3}$$

The relative agreement degree RAD_i of expert E_i (i = 1 to n) is given by:

$$RAD_i = \frac{AAD_i}{\sum_{i=1}^{n} AAD_i} \tag{4}$$

Finally, by weighing the relative agreement degree of each expert k by the degree of importance Gi_k (obtained through a questionnaire), the consensus coefficient for that expert can be calculated by equation (5).

$$CC_k = \frac{RAD_k * Gi_k}{\sum_{i=1}^{n} (RAD_i * Gi_i)} \tag{5}$$

The aggregated opinions are given by:

$$\tilde{N} = \sum_{i=1}^{n} CC_i \times \tilde{A}_i \tag{6}$$

In order to obtain a single value for each of the evaluated attributes – representing the failure expectation index, the dependency and adverse influence degrees, and the cognitive demands for each action, the *max* defuzzification method is applied [12].

For the case of cognitive demand, after normalization, and considering all cognitive demands for all actions, a Cognitive Demand Standard is built.

The overall failure possibility index for an action i (P_i) is obtained from its failure expectation index (F_i), its dependency degree on the previous action ($D_{i,(i-1)}$) and the adverse influence degree caused by failure of preceding actions ($T_{j,i}$; where $j < i$):

$$P_i = (1-(1-F_i)*(1-D_{i-(i-1)})*\prod_{j<i}(1-T_{j,i})) \tag{7}$$

The overall failure possibility for a procedure is obtained from the actions indexes:

$$P_{procedure} = (1-\prod_i (1-P_i)) \tag{8}$$

Finally, a degree of attendance of the operators to the Cognitive Demand Standard of each action is obtained. For that matter, the degree of attendance (OP_k) to each cognitive demand is multiplied by its demand standard (DS_k) and a weighted average R is then calculated:

$$R = \frac{\sum_{k=1}^{n} DS_k * OP_k}{\sum_{k=1}^{n} DS_k} \tag{9}$$

3 Decision Support System

The decision support system for human reliability analysis was developed as an Intranet application, maintaining all information in a centralized database and being accessible to all professionals involved in a characterization project: managers, experts, operators and psychologists.

The system is totally configurable to any company or business area and can de used for characterization and analysis at process and procedure levels, allowing for:

- human reliability characterization trials or *projects*, as they are called in the system, for different units of the company and different periods of time;
- the complete configuration of the PSFs to be considered, as well as the corresponding questionnaires to be applied to experts and workers, so

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that questions can be set up in accordance with the personnel's profile and company's characteristics;

- the complete configuration of the sequence of actions that make up the procedures to be analyzed;
- the on-line answering of EPIQ, PSF and procedure evaluation questionnaires by experts;
- the on-line answering of PSF questionnaires by operators;
- the on-line input of the psychometric test results for all workers by an authorized psychologist;
- the association of reference files to each project, such as manuals or norms that must be followed on the given human reliability characterization trial.

The system provides two sets of reports that give managers effective support on strategic decisions regarding the improvement of human reliability, and, consequently, the minimization of process failure.

The first set of reports, called *Process Reports*, comprises results from the process level characterization, including:

- Degree of importance of *PSFs*:
  The opinions of all experts with respect to the degree of importance of all PSFs are presented in a comparative chart.
- Average degree of attendance of PSFs:
  The average degrees of attendance of all PSFs, as seen by each operator, are presented in a comparative chart. A degree close to 1 indicates that, in the environment being evaluated, the operator considers that, in average, the quality standard is being met. On the other hand, a degree closer to 0 indicates that the operator evaluates that, in average, the quality standard is not being attended to. In this case, the possibility of failure for this worker is high.
- Distance to quality standard for all PSFs, as seen by a given operator:
  The quality standard for PSFs, established by the experts, represents the PSF *demand*, while the attendance degrees specified by a worker represent the PSF *offer*. This report shows graphically and in tabular form the distances between offer and demand. The greater the distance between the attendance degree and the quality standard, the more efforts and investments should the company dedicate to the given PSF to increase its attendance level. Factors with distances larger than 0.5 should merit special attention (Fig. 3).
- Inclusion coefficients for all PSFs, as seen by a given operator:
  This report shows the inclusion degree of the fuzzy set *quality standard* in the fuzzy set *attendance*, given by each operator. An inclusion coefficient close to 1 indicates that, in the environment being evaluated, the particular operator assimilation is greater than the quality standard.

The second set of reports, called *Procedure Reports*, present results from the procedure level characterization, including:

- Failure expectation for actions:
  The experts' aggregated expectations with regard to the failure of each action are presented. Failure expectations are presented together with the corresponding aggregated certainty degrees, which indicate the overall degree of sureness of the experts with respect to their opinions.

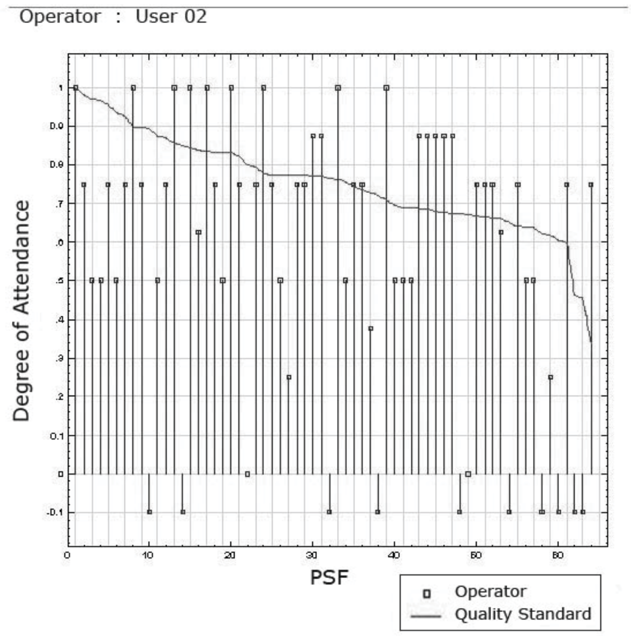

Figure 3: Distance to quality standard for all PSFs, as seen by a given operator.

- Dependency degree of actions:
  The experts' aggregated opinions on the dependency of each action on the previous one are presented. A degree close to 1 indicates that a failure on the previous action will most probably cause a failure on the current action. Actions with degrees higher than 0.6 deserve special attention. The dependency degrees are also presented together with the related aggregated certainty degrees.
- Influence of actions:
  In a matrix form, this report presents the experts' aggregated opinions about the possibility of a failure in each action having an influence on succeeding actions (Fig. 4). Degrees higher than 0.6 should be analyzed.

Action	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1.00	0.71	0.75	0.85	0.76	0.76	0.72	0.76	0.76	0.76	0.76	0.76	0.83	0.65	0.83	0.86	0.83	0.75
2		1.00	0.50	0.54	0.50	0.54	0.69	0.76	0.92	0.76	0.83	0.76	0.72	0.65	0.81	0.75	0.81	0.75
3			1.00	0.25	0.27	0.32	0.32	0.83	0.66	0.72	0.65	0.72	0.41	0.18	0.18	0.19	0.17	0.19
4				1.00	0.59	0.06	0.17	0.33	0.33	0.17	0.25	0.33	0.69	0.41	0.59	0.41	0.67	0.48
5					1.00	0.81	0.54	0.76	0.75	0.25	0.16	0.86	0.51	0.25	0.33	0.10	0.27	0.10
6						1.00	0.42	0.76	0.52	0.34	0.16	0.76	0.42	0.17	0.27	0.10	0.27	0.17
7							1.00	0.86	0.83	0.83	0.86	0.76	0.72	0.67	0.76	0.58	0.66	0.47
8								1.00	0.19	0.19	0.19	0.41	0.17	0.25	0.06	0.18	0.13	0.06
9									1.00	0.83	0.32	0.19	0.27	0.25	0.27	0.18	0.18	0.19
10										1.00	0.09	0.09	0.33	0.17	0.50	0.17	0.18	0.18
11											1.00	0.41	0.06	0.27	0.25	0.33	0.10	0.02
12												1.00	0.81	0.27	0.17	0.27	0.17	0.18
13													1.00	0.59	0.32	0.32	0.27	0.42
14														1.00	0.32	0.32	0.27	0.36
15															1.00	0.59	0.42	0.42
16																1.00	0.37	0.41
17																	1.00	0.52
18																		1.00

Figure 4: Influence of actions on subsequent ones

- Cognitive demands of actions:
  This report presents the degree with which a cognitive aspect is demanded for a worker to correctly execute an action (in the consensual opinion of all experts). The

degree of attendance of each cognitive factor for each operator is also shown. It indicates on which cognitive aspects the worker should receive training. Cognitive demands higher than 0.6 deserve special attention.

- Procedure overall failure possibility:
  The overall failure possibility indexes for the procedure and its actions are shown.

4 Case Study

An oil refinery was chosen as the unit for the case study, namely REDUC (Refinery of Duque de Caxias). This is located at Campos Elísios district, Rio de Janeiro, Brazil, and produces petrol, lubricants and other oil derivatives. The object of this case study is Procedure 1 (part of the Refinery Operation Process [9]), composed of the actions listed in Fig. 5.

The influence on each action by each cognitive factor was evaluated by 17 experts, who answered the questionnaire. The cognitive factors studied were: Anticipation, Attention, Calculation, Emotional State, Group Identification, Intelligence, Memory, Perception, Personality and Stress.

Taking as a basis the API 770 norm, two PSFs questionnaires, one for operators and another for experts, were configured for the considered unit. Both questionnaires correlate one question to each PSF. By using this specific questionnaire, an expert can evaluate which are the most critical PSFs. The system generates the PSFs quality standard by putting together the answers of all experts and weighing them based on EPIQ. By answering his questionnaire, an operator evaluates each PSF attendance. To evaluate the attendance of PSFs associated to cognitive factors, a questionnaire is used by a specialized psychologist, who analyses, based on standard psychology tests, how each interviewed operator is responding to each cognitive factor.

In total, 51 workers of the Operation Process answered the PSFs questionnaire, giving opinions about their working conditions. The 17 available experts answered the questionnaire in order to determine which PSFs had higher need to be attended. They also answered the EPIQ and the questionnaires about actions of Procedure 1, that is, expectation of failure, degree of dependency, influence on subsequent actions and cognitive demands. After all operators and experts of REDUC answered their respective questionnaires, the final reports could be consulted in the system by *project* administrators and managers.

The reports obtained in this case study are described below.

Report of Failure Expectation of Actions

From the report presented in Fig. 6, it is possible to conclude that the actions which had the higher failure expectation were: Return of Line to The Operation, Release of Line to The Maintenance, Return of Tank to The Operation, Aliments Change, and Area Survey.

Action Dependency Ratio Report

This report, depicted in Fig. 6, demonstrates that the actions which had higher dependency ratio on the preceding action were: Return of Pot Flare (18), Return of Line to The Operation (16), and Product Shipments to CIAS, BR/GEI, PETROFLEX (8).

Action Influence Report (see Fig. 4)

Based on this report, it is possible to conclude that actions Demands (1) and Aliments Change (7) have more influence on subsequent actions than any other. Additionally, Product Shipments to CIAS, BR/GEI, PETROFLEX (8) and Loading of Trucks (12) are most affected than other actions.

Action		Failure Expectation	Certainty Degree
1	Demands	0.0000	1.0000
2	Area Survey	0.3042	1.0000
3	Measurements and Sampling	0.2370	0.7865
4	Drainages	0.1043	0.7291
5	Pumps Starts	0.0269	0.9490
6	Pumps Stops	0.0269	0.8901
7	Aliments Change	0.4313	0.8901
8	PETROFLEX	0.2500	1.0000
9	Exchange Loads of Units	0.2298	1.0000
10	Exchange Receipt of Units	0.2298	0.9314
11	Gravitations	0.0269	0.9314
12	Loading of Trucks	0.1367	0.8901
13	Release of Equipments to Maintenance	0.2500	0.0784
14	Return of Tank to The Operation	0.4458	0.6542
15	Release of Line to The Maintenance	0.4844	0.6542
16	Return of Line to The Operation	0.4844	0.6542
17	Release of Pot Flare	0.2772	0.8901
18	Return of Pot Flare	0.2772	0.8901

Figure 5: Failure Expectation of Actions for Procedure 1.

Action	Dependency Ratio	Certainty Degree
1	--	1.0000
2	0.5334	1.0000
3	0.3855	0.7865
4	0.4215	0.7291
5	0.3336	0.9490
6	0.3067	0.8901
7	0.2840	0.8901
8	**0.6192**	1.0000
9	0.0303	1.0000
10	0.5510	0.9314
11	0.4388	0.9314
12	0.1043	0.8901
13	0.0378	0.0784
14	0.5055	0.6542
15	0.3623	0.6542
16	**0.7674**	0.6542
17	0.5334	0.8901
18	**0.9334**	0.8901

Figure 6: Dependency ratio between each action and the preceding one

Cognitive Demand Attendance Degree of Actions

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This report, shown in Fig. 7, is used for comparison between the cognitive demand of actions of Procedure 1 and the attendance of each worker. Therefore, a manager can infer whether an operator is capable of executing the actions he/she is assigned to. For instance, it can be seen in Fig. 7 that the given operator does not attend the Anticipation requirement of actions 9, 13 and 16.

Global Index of Failure Possibility of Actions

This report, shown in Fig. 8, indicates the possibility of failure of each action, considering every influence it experiences (such as influences and dependencies from other actions, failure expectation). The system allows the manager to choose the cut level of the influence to be considered. A higher cut level means that the preceding actions which have low influence will not be considered. As a result, in this case study, a 0.6 cut level returns the mid and final actions as the ones with the highest failure possibilities. In opposition, a 0.9 cut level returns a more disperse failure profile, since it only considers the preceding actions that have large influence on the action itself.

	Anticipation	Attention	Calculation	Emotive State	Group Id	Intelligence	Memory	Perception	Personality	Stress
1	0.600	**0.615**	0.262	**0.645**	0.523	0.466	**0.800**	0.458	**0.724**	0.472
2	**0.700**	**0.779**	0.047	**0.700**	0.600	**0.615**	**0.700**	**0.818**	**0.713**	0.577
3	0.600	**0.949**	**0.770**	**0.665**	0.600	**0.690**	**0.700**	**0.738**	**0.700**	**0.624**
4	0.516	**0.762**	0.431	0.521	0.581	0.566	0.100	**0.636**	0.455	**0.705**
5	**0.614**	**0.716**	0.554	**0.633**	0.414	0.600	0.509	**0.905**	0.570	0.494
6	**0.614**	**0.734**	0.197	0.509	0.413	0.600	0.414	**0.843**	**0.638**	0.410
7	**0.781**	**0.955**	**0.700**	**0.667**	**0.762**	**0.638**	**0.732**	**0.734**	**0.694**	**0.662**
8	**0.800**	**0.941**	**0.769**	**0.667**	**0.669**	**0.609**	**0.613**	**0.764**	**0.686**	**0.641**
9	**0.973**	**1.000**	**0.700**	**0.654**	**0.800**	**0.668**	**0.620**	**0.782**	**0.700**	0.600
10	**0.800**	0.000	0.539	**0.700**	0.000	**0.800**	**0.800**	**0.700**	**0.700**	0.600
11	**0.700**	**0.658**	**0.700**	**0.700**	0.000	0.570	0.558	**0.666**	**0.700**	0.600
12	**0.843**	**0.805**	**0.632**	**0.700**	**0.773**	0.600	0.600	**0.669**	**0.700**	**0.628**
13	**0.881**	**0.863**	0.600	**0.700**	**0.604**	**0.721**	**0.854**	**0.762**	**0.691**	0.403
14	**0.822**	**0.884**	0.390	0.533	**0.613**	**0.679**	**0.939**	**0.790**	**0.689**	0.500
15	**0.858**	**0.812**	**0.700**	**0.632**	**0.690**	**0.700**	**0.868**	**0.800**	**0.666**	0.500
16	**0.973**	**0.900**	**0.700**	**0.632**	**0.690**	**0.679**	**0.895**	**0.810**	**0.689**	0.500
17	**0.869**	**0.939**	**0.647**	0.579	**0.791**	**0.692**	**0.868**	**0.889**	**0.666**	0.513
18	**0.869**	**0.939**	**0.647**	**0.718**	**0.791**	**0.628**	**0.869**	**0.887**	**0.666**	**0.628**
Attendance										
User 35	**0.875**	**0.875**	--	--	**1.000**	0.500	--	--	--	0.125

Figure 7: Cognitive Demand Attendance

5 Conclusions

An innovative system for the evaluation of human reliability in industry has been presented. The approach taken makes use of fuzzy sets, so that experts and operators' opinions can be translated into mathematical terms. As a consequence, a Quality Standard (QS) can be established and the attendance to performance shaping factors can be evaluated.

This system can be used at both process and procedure (consisting of series of actions) levels and produces several reports that help managers to make decisions aimed at reducing the possibility of human errors. A case study considered a unit of a Petrobras (Brazilian Oil Company) refinery, where the system has been actually applied to.

Acknowledgment

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Action	Global Index of Failure	
	(Cut Level 0,6)	(Cut Level 0,9)
1	0.0000	0.0000
2	0.5334	0.5334
3	0.4632	0.4632
4	0.4495	0.4495
5	0.3416	0.3416
6	0.5036	0.3131
7	0.6444	0.3807
8	0.9759	0.6554
9	0.9083	0.5796
10	0.9841	0.6108
11	0.9049	0.4480
12	0.9309	0.1592
13	0.9586	0.0761
14	0.8948	0.5223
15	0.8946	0.5236
16	0.9210	0.8264
17	0.9217	0.6403
18	0.9703	0.9452

Figure 8: Global Index of Failure Possibility of Actions.

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